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A Computer Based Information System for Patient Care

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I. INTRODUCTION

Since June, 1964, a Control Data 3200 computer system has been installed in the Latter Day Saints Hospital in Salt Lake City, Utah. This system in its inception was used to develop research programs and time-sharing software for use by the medical community in the Salt Lake City area. As a result, a software and hardware system called MEDLAB has been developed [1, 2]. Using this system, research

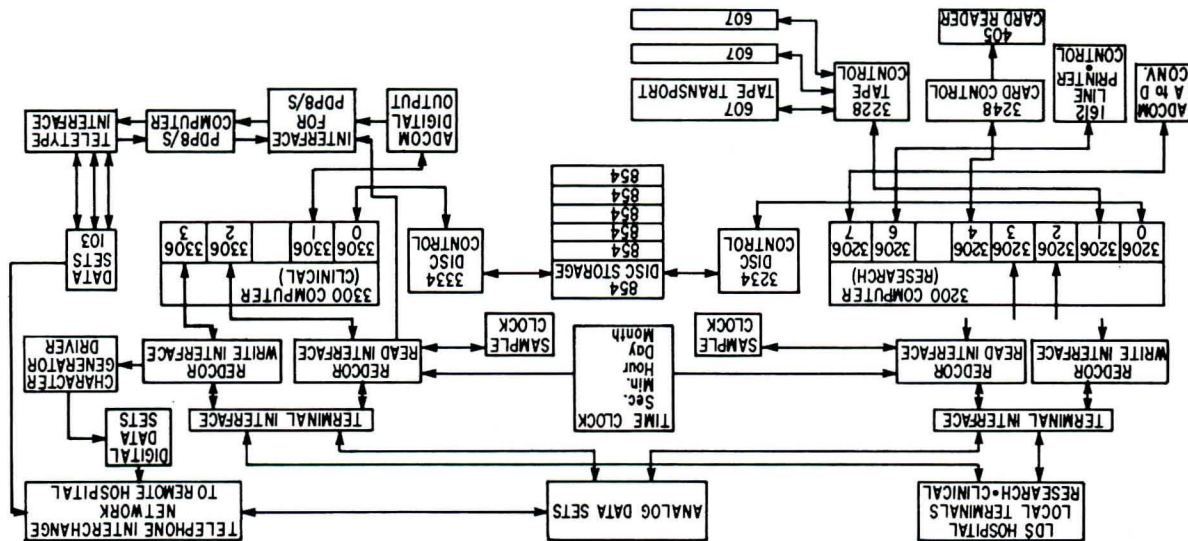
* Portions of this chapter have been adapted from the following articles: "Computer System for Research and Clinical Application to Medicine," by T. Allan Pryor, Reed M. Gardner and W. Clinton Day, published in AFIPS-Conference Proceedings, 33, 1968; "Experiences with Computer-Based Patient Monitoring," by Homer R. Warner, published in Anesthesia and Analgesia, 47, No. 5, Sept.-Oct. 1968; and, "A 'Link Trainer' for the Coronary Care Unit," by Homer R. Warner and Albert Budkin, published in Computers and Biomedical Research, 2, No. 2, Oct. 1968, and reproduced by permission of the publishers.

programs were developed for cardiovascular studies. It soon became apparent that the programs which were being developed could also be used in a clinical environment. In recent years, as the computer system was expanded, clinical application became increasingly important. At the present time the system is used in a variety of ways, including admission screening, maintenance of patient records, patient monitoring in intensive care units, and training of coronary-care nurses. This chapter presents the major hardware and software features of the system and describes the major areas of clinical application.

II HARDWARE CONFIGURATION

The system used for both research and clinical applications is made up of three computers located at the L. D. S. Hospital. A block diagram of the system is shown in Fig. 1 which shows the two computers - a CDC 3200 and 3300, the 3200 being used for research and program debugging and the 3300 being used strictly for operational clinical applications: the small Digital Equipment Corporation PDP-8/S computer is used as a teletype buffer driver to provide hard copy at distant hospital sites. Although the 3300 has expansion capabilities which the 3200 does not have such as paging memory, memory protect, etc., the 3300 used has essentially the same capability as the 3200 computer. Therefore, both machines are hardware and software compatible and communicate through common disc units.

Fig. 1. System block diagram



There are three pieces of equipment identical on each machine which are critical for hardware and software interchangeability (listed as follows).

- (1) The disc storage units.
- (2) The REDCOR Corporation read and write interfaces, which are the adapters for communicating with the remote terminals and the handling of the physiological signals coming either from a patient or an experimental set up. The read interfaces for both machines are identical and analog signals are presented in parallel to the analog multiplexers of both interfaces. Thus, a program can be debugged, checked out and made operational on the 3200 research system with no change of channels or program. If the analog-to-digital (A-to-D) converter or computer system for the clinical system fails, the clinical operating system can be transferred to the 3200 machine with a minimum of rewiring (approximately 10 minutes required for changeover after the problem is diagnosed) and the assurance that the analog signals will be correct.
- (3) The write interfaces on both machines are identical and are connected such that they can be transferred from one machine to the other with a minimum of difficulty (approximately 10 minutes).

The two machines are different in their hardware configurations since the 3200 is used for program compilation,

printing, and magnetic tape capability for program and data storage. The extra peripheral equipment on the research machine includes a 1000-card-per-minute card reader, a 1000-line-per-minute printer, three high-speed magnetic tapes, and one special-purpose high-speed A-to-D converter. The 3300, or clinical machine, on the other hand, has a special output interface for the small PDP-8/S computer used to drive teletypes at the remote sites for hard-copy reporting of clinical and experimental information. Both machines are capable of operating remote terminals both from sites within the hospital and remote sites at other hospitals, experimental laboratories, and clinics.

1. Remote Terminals

Figure 2 shows a photograph of a typical remote terminal through which an experimenter communicates with the computer [3]. This remote terminal consists of a Tektronix 601 memory display unit, control and timing circuits for operation of this display unit, a decimal keyboard, and two 12-bit octal thumbwheel switches for coding information into the computer. Also shown on the front panel are indicator lights which tell the operator the state of the computer, the state of his program, and various other indications.

In a typical operation, the user calls a program by dialing a code into the octal switches, then presses the CALL button which interrupts the computer. The computer reads the octal switch and displays instructions back to the operator on the face of the memory display unit. The display unit is

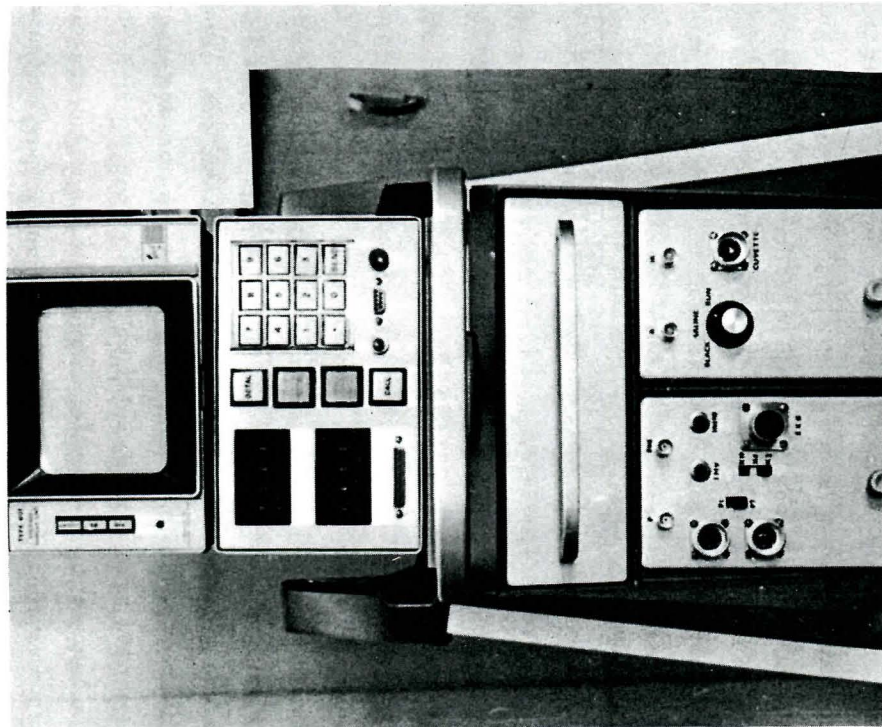


Fig. 2. Remote terminal with instrumentation.

capable of displaying 400 characters in a 25-column by 16-row pattern or graphical information with a capability of 512 horizontal and 512 vertical dots. In addition to its capacity as a remote computer display terminal, the terminal can also be used as a conventional three-channel memory oscilloscope by

pressing a push-button switch on the front panel. This feature allows the operator to quickly check signal-level qualities to be presented to the computer and insure that they are within range of the A-to-D converter and of adequate quality for the desired computer analysis. The display will revert from a conventional oscilloscope to a computer display terminal upon receiving an erase pulse from the computer, thus assuring that no computer-generated information is lost while the operator is viewing wave forms.

The processing of analog signals is presently carried out independent of the display terminal. As a standard package, each laboratory or clinical area is assigned three analog channels. These three channels are used for multiple purposes. For example, the three channels could be carrying pressure information, electrocardiographic information, densitometry information, etc., depending on the requirement of the user. This three-channel requirement was primarily determined by an electrocardiographic analysis program where three simultaneous lead signals are necessary. A second reason for making three analog channels a standard configuration is that three-channel data sets for telecommunication to distant sites are available for processing of data from remote hospitals.

The remote terminals with instrumentation can be constructed for a cost of about \$3000; a character generator added for operation of remote sites costs an additional \$1200. With the capability of both alphanumeric and graphical functions, this terminal becomes an extremely flexible convenient module for use in both clinical and experimental applications.

Since most of the physiologic signals are analog, it was necessary to develop extensive front-end signal conditioning equipment for the computer operation. An objective in the development of the front-end equipment was to provide extremely stable, highly reliable instrumentation, such that a person with a minimum of instruction and training could use it. The lower part of Fig. 2 shows the front panel of a typical instrumentation package. Note that there are no control knobs for adjusting gain or bias of the analog signals from the transducers and that there are a minimum number of control switches for operator use.

The analog front-end system is made up primarily of integrated-circuit operational amplifiers, with all signals being amplified from their low-level condition to a high-level (+10 volts) condition for transmission to the computer, either over hardware connection or a telecommunication link. In each case, signals are conditioned for optimum use by the computer and by the telecommunication link by amplifying and adjusting the offset for full-scale capability of computer and communication link.

Experience has shown that minimizing the number of controls and adjustments makes the system easier to use, both by experienced and nonexperienced operators, and also increases the confidence of the operating personnel. As a typical example of an instrumentation application where this type of approach has been used, consider the pressure transducer amplifier which amplifies signals from a balanced Wheatstone-bridge strain gage. The gage itself can be

balanced, the amplifier or amplifiers could each have a separate offset control, the gage excitation could be varied, the amplifier gain could be varied, and so on. To minimize the problems in setup of a pressure transducer, only one control is provided and is made an integral part of the transducer system. The excitation voltage on the gage is fixed, the sensitivity of all the strain gages have been calibrated to a standard level and all pressure amplifiers are set up with the standard gains. A fixed offset has been programmed into the amplifying system and the only adjustment that need be made by the user is gage balance which compensates for varying fluid levels of the patient. Therefore, a pressure system which is usually complicated and difficult to handle becomes a simple set up procedure which a nurse or inexperienced technician can adequately handle and get results that are technically adequate and, in fact, as good as an experienced operator can obtain.

As can be seen from the foregoing discussion, the computer system has been designed with both a research investigator and a clinical investigator in mind, with standard packages designed and constructed which aid both. The system is also easily adaptable to special-purpose experimentation with signal levels that can be conditioned with a great amount of flexibility for the occasional user who has special requirements for signal levels, sampling rates, and timing.

Operation of terminals from remote hospitals is made over voice-grade direct-distance dial compatible telephone communication link. As far as the user is concerned, opera-

tion from a remote hospital is essentially the same as operating a local terminal.

The basic remote terminal, which is not much larger than the 201 data set (Fig. 2), is completely transportable and can be taken anywhere telephone communication facilities are available and used to communicate with the MEDLAB system. Applications for stand-alone communication terminals of this type are expected in tumor registry programs, radiation treatment planning, and other areas where analog signals are not necessary. When analog signals are required, Bell System data sets 604A and 604B, an analog transmitter and receiver, respectively, are used to send three channels of analog information simultaneously. The analog data bandwidth of these FM multiplexed channels is dc to 100 cycles for each channel. Cross-talk and signal-to-noise characteristics and bandwidth of these channels is adequate for transmission of most clinical physiologic information. The requirements for three channels are dictated by the vectorcardiographic system which requires three simultaneous channels of ECG. With a slight modification of this system it is possible to use a touch-tone telephone keyboard and a 604A/B, 401J data set configuration to transmit electrocardiograms and other physiologic data from any patient room within a hospital by installing phone jacks in the rooms and using the internal television distribution system of the hospital to transmit instructions and results to the operator on the television receiver located in the patient room.

A "program-line" connection is operational between the neurophysiology research laboratory at a remote hospital.

This type line is one which is commonly used by FM music stations and is conditioned to have "flat" frequency response from 50 Hz to 8 kHz making it ideally suited for transmission of action potentials.

Presently, there are systems in four hospitals using the communications terminals and one additional hospital using a hardwire connection. Plans call for region-wide screening clinics to be conducted by state, local, and private health organizations. With these terminals, health services can be provided to remote communities that heretofore were available only to patients at major hospitals.

III. SOFTWARE CONFIGURATION: THE MEDLAB SYSTEM

Design of a system for servicing physiologic needs presents some interesting problems. Computing speed is essential to accomplish certain tasks, and yet, on the other hand, some physiologic events occur very slowly compared to the computing time required to keep up with them. Thus, if the user is to have the computer when he needs it for this kind of work, it is necessary that a system be devised for rapid switching among programs. Such a time-sharing scheme has among programs. Such a scheme, called time-sharing, has been implemented on the Control Data 3200 at the Latter Day Saints Hospital in Salt Lake City.

A. The Time-Sharing Monitor

The time-sharing monitor, called MEDLAB [2], resides in the memory of the central computer which, in turn, communicates with a variety of peripheral devices. Programs

or instructions are entered into the computer initially through a card reader and are then stored on magnetic discs from which they can be called into memory from any of the remote stations. Data on patients in the hospital are also stored on magnetic discs for ready access. When a patient is discharged, his record is copied onto a library tape, where it is stored permanently. Program listings and reports are generated on a high-speed printer at the rate of 1000 lines per minute.

The analog-to-digital and digital-to-analog conversion system forms the basic link to the remote stations. Presently, there are 19 remote stations in five different hospitals attached to our system. To each of these users operating from his remote station, the computer appears to be under his command and he can operate essentially independently of other users on the system.

The 32,000 words of core memory are allocated as follows to accommodate multiprogramming: in the top 5000 words of memory is the monitor program, which contains not only the instructions that control switching among the programs in memory, swapping of programs in and out of memory, and sampling of data, but also a set of reentrant subroutines which can be used by any of the user programs to accomplish such tasks as writing on the oscilloscope, converting numbers from binary to decimal, and inserting answers into messages. This latter function considerably reduces the programming the user must do to accomplish his goals.

From four to six real-time programs (up to 2000 words in length for any one overlay), which are actively

sampling data, may be in memory at any one time, and programs not sampling may be swapped onto discs temporarily while other programs are being run. The lower part of core memory is reserved for compilation and assembly of new programs and execution of FORTRAN programs, which may or may not communicate with the real world through one of the remote stations. Those that do communicate with the real world carry a higher priority than those that do not, in the sequence in which jobs are executed. The organization of data on the magnetic discs, whether from experimental animals or patients, follows a common format.

B. Differences Between the Research and Clinical Systems

The software available on the 3200 (research) system and that on the 3300 (clinical) system are quite similar, but some important differences exist. A major difference is the type of program which can be run under either system. On the 3300 system, which is used for clinical applications, there are 12 partitions within core memory, each partition being approximately 2000 words in length. Only those programs which are designated clinical real-time programs and have been written in assembly language are allowed to run within any of the 12 partitions. Since the user can have only 2000 words of core at any time, most programs are written as a series of overlays to be read in as needed into the same partition. These programs must have reached a high degree of reliability before being allowed to run on the clinical system. The clinical executive monitor contains a dictionary of the programs allowed, and if a program is not in that

dictionary a message is written on the display unit at the terminal indicating that the program is not allowed. No debugging of programs is allowed on the clinical system. All debugging must be performed on the research system.

Software-wise there is no interaction between the research system and the clinical system. The research system is unaware of whether the data generated on any disc is generated by a program being run on the research or the clinical system. All data which are generated by either machine and stored on disc are accessible by the research system for report generation on the line printer.

C. Compilation of Data

This file organization is designed to provide for addition of new types of information in the future and still maintain a basic format, so that the same search, edit, and analysis programs can be shared by a wide variety of users. At the start of each file is a count which keeps track of how many entries are currently in the file and where the next word of data is to be stored. Entry of a field of data is preceded and ended by a code which uniquely defines the kind of data and the number of data words in the field. The second word is the time and date, read automatically by the computer from an external clock when the entry is made. Thus, any user may define a new field of any length and add it to this file.

D. Examples of Data Code

A general program has been written for introducing a variety of physiologic measurements into the computer, which

is now in use in several diagnostic heart-catheterization laboratories connected to our system. This permits the user to initialize a file on a patient and call a variety of subprograms to analyze data in any sequence. To do this, a four-digit rotary switch on the remote console is used. The first digit indicates the type of analysis to be performed. For instance, 0 is an oxygen-saturation measurement, 1 is a pressure wave, 2 is a dye curve, and so forth. The second digit indicates the state of the patient. For instance, 0 means the patient is at rest, breathing room air, 3 means the patient is breathing oxygen during exercise, and so forth. The last two digits are used to indicate the position of the catheter tip in the circulation.

The operator dials the desired code and presses the interrupt. The code is interpreted by the computer and this interpretation is presented back on the oscilloscope for confirmation by the operator. If one or more of the digits was in error, the code is redialed and sent again. Until the same code is sent twice, the program will not proceed. When the data are on the line (for instance, the pressure to be measured appears free of artifact) the interrupt is pressed once again, and the analysis begins. The results are displayed back immediately to the operator, who may choose to discard the data or save them by writing them on the disc to be included in a later report.

Figure 3 shows the presentation made on the oscilloscope to the operator on completion of analysis of an indicator-dilution curve. At the bottom is the recorded curve plotted back as milligrams per liter and superimposed on this, the

C.O. 4.16
M.I. 0.97
A.T. 11.50
B.T. 5.0
M.C. 20.5
C.V. 1.39



Fig. 3. Information displayed to operator within 1 second after completion of sampling following injection of indocyanine green dye.

experimental extrapolation carried out by the computer, so that the operator has some means for evaluating the adequacy of the analysis.

At the top are the calculated values: cardiac output is 4.16 L./minute. "M.I." is the mitral insufficiency index, which should be 1 or greater in a normal subject, and measures the skewness of the curve; this is a useful empiric index for the presence of mitral insufficiency in the absence of a left-to-right shunt. Next are shown appearance time, buildup time, mean circulation time, and central blood volume. At any time during the procedure and at the end of the procedure the operator may review and edit the data accumulated on the disc.

Figure 4 shows one page of data presented on the face of the oscilloscope. The "1" on the first line indicates that the patient is exercising and an oxygen saturation reading of 101 was obtained with the catheter tip in the "wedge" position.

1WE 101
1PT 52/ 26 39
1RV 84/ 15 20
2RD 100
ORD 97/ 64 77
ORD 93
OC.O. 4.16
M.I. 1.1
A.T. 12.25
B.T. 4.75
M.C. 20.0
C.V. 1.38

Fig. 4. One page of data displayed during edit routine.

The next reading is a measurement of pressure in the pulmonary trunk, with the systolic, diastolic, and mean pressures shown. At the bottom is a cardiac output measurement by the dye method.

Pressing a zero causes the next page of data to be presented on the oscilloscope. Values may be deleted or altered by the operator, who may request any number of copies of a printed report upon completion of his editing, including a computer-generated summary of the abnormalities present. Thus, before the catheter is removed from the circulation, the data are completely analyzed, and if any question exists about the significance of some of the data, repeat measurements can readily be made. A direct extension of these techniques is their application in the operating room and at the bedside.

IV. APPLICATIONS TO PRE- AND POSTSURGICAL MONITORING

On the afternoon before surgery, the patient is taken to a special laboratory equipped with a remote computer station, where a tiny central aortic pressure catheter is introduced by

a technician. Using a special armboard* which is floor mounted and can be positioned next to any type of bed or table, the patient's wrist is extended and local anesthetic is introduced around the radial artery. Then a thin-walled 18-gauge needle, connected by a special catheter assembly[†] to a strain-gauge manometer, is introduced into the artery percutaneously by a technician while visually observing the pressure wave form on an oscilloscope.

When the needle enters the artery, the solid plastic casing surrounding the catheter is withdrawn, automatically advancing the catheter up the artery to the subclavian. No fluoroscopic control is needed, since the catheter will not pass beyond this point, due to the sharp angulation of the artery and the rigidity of the catheter. When this point is reached, the pressure wave disappears and the catheter is withdrawn two centimeters, where it remains for the rest of the study. The needle is withdrawn from the artery over the catheter, and control measurements are performed.

A cardiac output determination may be made by injecting dye into the antecubital vein and sampling through this needle prior to introduction of the catheter. However, in many patients, since changes in cardiac output are of primary interest, no absolute calibration against the dye method is performed. On completion of the control studies, the catheter is removed from the strain gauge, filled with heparin, and

* SAFLEX, Romney Engineering & Manufacturing Company, Salt Lake City, Utah.

[†] Sorenson Research Company, Salt Lake City, Utah

dead-ended. The catheter assembly is then taped to the forearm and the patient is returned to his room. These catheters have been left in place as long as 10 days, and in over 400 such procedures, most of which have been done by technicians, no significant complications have resulted.

The next morning the patient goes to surgery, where his catheter is once again connected to a pressure transducer at a remote station in the operating room. Pressure calibration is repeated by sampling the strain-gauge output when it is exposed to 0 and 100 mm Hg pressure from a mercury manometer through a saline flush system. From that point on, the anesthesiologist can obtain a measurement of pressure, stroke volume, heart rate, cardiac output, and resistance by merely pressing an interrupt button on the console at his side; the results are displayed back to him on the oscilloscope of that console.

Other programs developed by Dr. William M. Stauffer, in our laboratory, permit the anesthesiologist to enter other pertinent information during the course of the procedure, such as drugs administered and comments about the patient, which become part of the computer-based record and can be printed out at the end of the operation in the form of an integrated anesthesiology record on this patient.

After surgery, the patient is taken to a six-bed intensive care ward which contains a remote console, as shown in Fig. 5.

At the top of this figure is shown a standard remote computer input station with its memory oscilloscope, four-

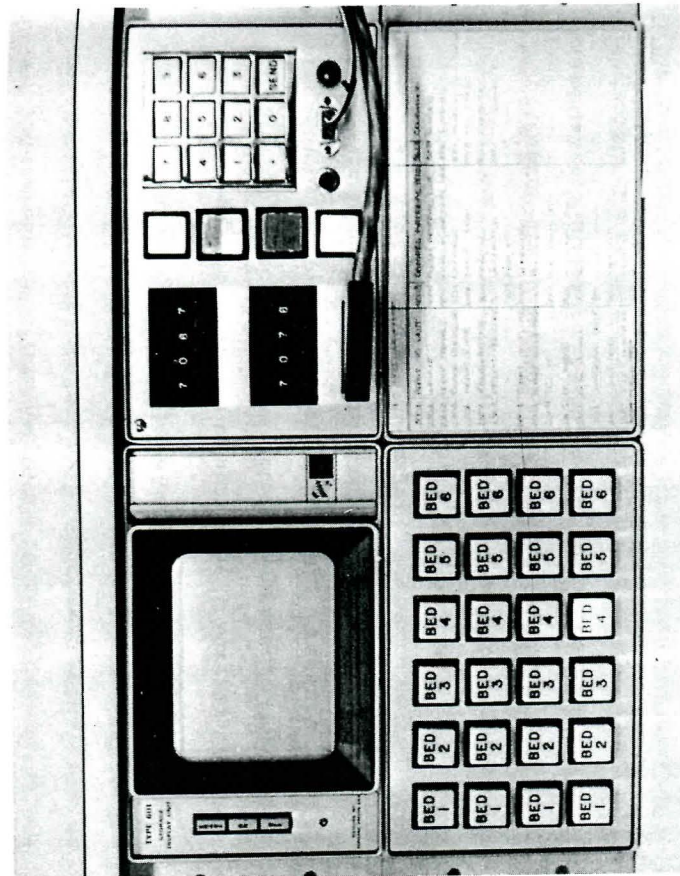


Fig. 5. Remote console located at nursing station in the intensive care ward.

digit switch, and 12-key decimal keyboard. This scope can be used both for computer writeout and for direct display of pressure or electrocardiographic wave forms from any bed. At the bottom is a second unit containing a bank of lights and a row of push-button switches used to indicate the bed from which wave forms are to be displayed. There are three lights

for each of the six beds. The green light indicates the computer is actively sampling data from that bed. The red and yellow lights are used to alert the nurse that a change has occurred in the patient occupying that bed.

To initiate a monitoring schedule on a patient, the nurse or doctor presses the call button and then indicates the bed number by pressing the corresponding number on the decimal keyboard. The computer displays a list of options, one of which is to initialize a schedule on the patient. When the nurse presses the number corresponding to this option, the computer will sample the next 64 heart beats on that patient and determine the mean value and standard error (S.E.) of the mean of each of the variables calculated from the central aortic pressure pulse, as shown in Fig. 6.

17.35		
S.V.	52	5
H.R.	83	8
C.O.	44	6
SDUR	235	25
RST	15	4
SY P	106	6
DI P	66	4
V.P.	14	
R.A.	2	
R.R.	15	
BED NUMBER	5	
0	END, OR	BED NO.

Fig. 6. Display of mean values and standard error of the mean for stroke volume (S.V.), heart rate (H.R.), cardiac output (C.O.), duration of systole (SDUR), resistance (RST), systolic pressure (SY P), and diastolic pressure (DI P) measured from central aortic pressure wave form on 64 heart cycles. Mean venous pressure (V.P.), respiratory amplitude (R.A.), and respiratory rate (R.R.) are derived from central venous pressure signal.

In the first column are the mean values and in the second column, the S. E. of the mean which then serves as a basis for judging subsequent measurements on that patient. If any subsequent measurement exceeds the expected mean value for any variable by >3 S. E., a red light turns on.

More subtle changes may be detected if they are systematic. If, for instance, stroke volume differs from its expected mean value by 1 S. E. in the same direction on three successive measurements, a trend is established and a yellow light turns on. When a red or yellow light appears, the nurse or doctor can press that light, which is also an interrupt switch, and cause the computer to display an interpretation of that light back on the memory oscilloscope, as shown in Fig. 7.

In this case (Fig. 7), the variable furthest out of tolerance is diastolic pressure. The last value, measured at 18:06, was 104 mm Hg, while the baseline value was 88 mm Hg. To explain this rise in diastolic pressure, the nurse may choose option 1, allowing her to enter clinical information which she thinks might be pertinent to the physiologic observation. This is entered by indicating whether it is a procedure, a condition, or medication. Following this, an appropriate list under each of these categories is presented and the nurse once again chooses her specific entry from that list. This information is then stored on disc as part of the patient's record for later correlation with the physiologic information.

By pressing option 2, the nurse can review the course of the patient over any arbitrary period of time. Under this

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BED 3
DI P
LAST 18. 6
    104
BASE 18. 2
    88
1 EXPLAIN
2 REVIEW
3 IGNORE
4 NEW BASE
5 WAVES

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Fig. 7. Message displayed when the nurse presses red light to explain physiologic variation in a patient.

option the data are presented as shown in Fig. 8. The first column of numbers are the values for each of the variables measured at 17:37, and the second column are the values measured 2 min earlier. The user can page forward or backward, displaying values in this fashion to obtain information as to the time-course of events leading up to the physiologic change.

Any data that differ significantly from the baseline values are saved in the patient's file. The scheduling of measurements is done by the computer through an algorithm, which adjusts the interval between samples according to how stable the patient is. For example, if the patient is doing well, the interval between samples is made longer up to a maximum of 16 minutes, but if a change occurs in the patient's condition, that interval is shortened to 2 minutes on the next reading.

Another way in which the data may be reviewed by the nurse or doctor is to request a plot on the oscilloscope of the time-course of one or more variables over a time interval


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17.37 17.35
S.V. 53 52
H.R. 77 83
C.O. 42 44
SDUR 231 235
RST 16 15
SY P 109 106
DI P 65 66
V.P. 15 14
R.A. 1 2
R.R. 16 15
BED NUMBER 5
0 BAK.1 FOR.9 DEL
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Fig. 8. Oscilloscope display under a review data option of program, showing two sets of readings 2 minutes apart for comparison.

requested by the user. Still another available aid for interpretation of physiologic change is provided through an option which permits the time-course of arterial pressure averaged over 16 heart beats at the time of the last measurement to be displayed on the oscilloscope and superimposed on the waveform recorded at the time of the baseline measurement. Changes in contour of these wave forms have provided useful information in detecting conditions, such as blood loss, at an early stage.

At the end of each 8-hour shift, a summary report is printed for each patient showing the mode values of each variable and the comments entered by the nurses. When a patient is discharged from the ward, his data are copied from disc to library tape and saved for subsequent analysis.

V. PATIENT SCREENING

An important part of the total system is a patient screening program. Every patient who is admitted to the

L. D. S. Hospital, with the exception of maternity and emergency patients, is screened using this program. When the patient arrives at the hospital and registers in the admitting office he is given a hospital record number. This number is used by the computer system to generate a file of data for the patient. Once the patient has received his registration forms he is brought to an admitting laboratory where two samples of blood and a urine sample are taken for analysis in the chemistry laboratory. On leaving the admitting laboratory the patient is brought to the computer screening laboratory. A file is initiated on the patient by entering the patient's hospital number on the decimal keyboard at the terminal. A nurse measures the patient's blood pressure, temperature, respiration rate and enters these parameters along with age, height, and weight in the patient's file.

Two on-line computer tests are then performed on the patient. The first is a maximum breathing test where the patient is required to take a deep breath and blow into a spirometer which measures both the total volume expired by the patient (forced vital capacity), the volume expired after 1 second and two flow rates during the maximum expiration. The analog signal generated by a potentiometer connected to the spirometer is sent directly to the computer. Corrections for temperature, barometric pressure, and calibration factors are made by the computer and the results presented on the display unit within 2 seconds after the test. Once the patient has successfully performed this test, which usually requires blowing into the spirometer at least twice in order to obtain the best possible results, the patient is given a computerized

electrocardiogram (ECG) with the computer sampling the output of the three vector signals from the ECG amplifier. This test requires a series of eight electrocardiographic leads to be connected to the patient. These leads are resolved by the amplifier into an orthogonal lead system used for the measuring of the electrical activity of the heart. The program performs a pattern recognition on the data collected and reports back to the screening technicians a classification of an ECG pattern. This information is also stored in the patient's file. Once the patient has completed his electrocardiogram he is taken to his room. Total time for these two tests is approximately 5 minutes with the computer being used for about 1 minute.

Other information entered into the patient's file includes the results of the urine analysis and the hematology analysis, and the blood chemistry tests run on a 12-channel autoanalyzer. The 12-channel autoanalyzer is operated as an on-line terminal which allows the computer to sample its output and store the results directly into the patient's file. The urinalysis, as well as the hematology results, are entered into the patient's file through the keyboard at a remote terminal.

At the end of the day the technicians generate a report from the patient's data by punching a card with the patient's name and hospital number. The report generated for each patient contains all the data which had been entered, either automatically by the computer or keyed in from one of the remote terminals. The program prints out the test results as well as a problem list, that is, a listing of all values which

are outside normal limits. The reports are then distributed to the nursing stations and placed on the patient's charts. Subsequent data gathered on the patient during his stay in the hospital are also recorded in the patient's file by the computer. At time of discharge the file is taken from the active file, which is stored on one of the magnetic discs, and transferred to magnetic tape in the inactive file. At this time, or shortly after, a discharge diagnosis is placed on the patient's record. When the patient is readmitted to the hospital his record is retrieved and pertinent information returned to the disc in the active file.

VI. A TEACHING-TESTING PROGRAM FOR CORONARY-CARE NURSES

Any of the remote stations at the L. D. S. Hospital can be used for teaching coronary-care nurses [4-7] using a program developed for this purpose. The program simulates the rhythm disturbances a patient with an acute episode of ischemic heart disease might develop during his stay in a coronary-care unit. It displays an electrocardiogram across the face of the scope in the same way the nurse sees it on the oscilloscopes of the intensive care unit, with the cathode ray sweep inscribing the graph from left to right as the electrocardiogram is being generated by the computer. First, a normal sinus rhythm is displayed when the program is called from the remote station. On the second sweep, an abnormal tracing is presented to the user. This tracing is randomly selected by the computer from a transition matrix containing 15 arrhythmias. External noise can be simulated by the

computer and may appear at random in the tracings as 60-cycle interference, muscle tremor, or, in some cases, even suggesting a loose electrode. Below the tracing being displayed a message on the scope offers the information that three possible courses of action can be taken: (1) a medication can be given, (2) a procedure can be carried out, or (3) more information about the patient's condition can be obtained (Fig. 9). The nurse faces a series of problems as the case is being presented to her — the first of these is to diagnose the condition of the patient. If she cannot diagnose the rhythm being displayed, one of the above options allows her to call for a consultation which causes the diagnosis to be displayed in the form of a message on the scope above the tracing. Still another option allows the student to ask for the optimal treatment and cause this to be displayed. She pays a price for

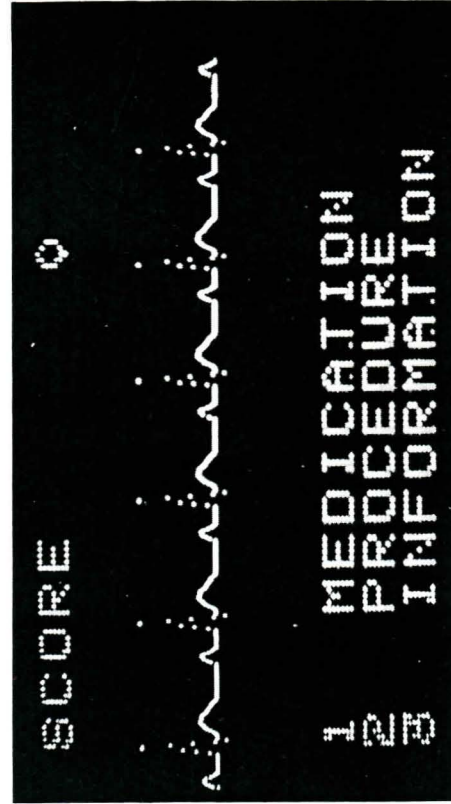


Fig. 9. Electrocardiogram and options for courses of action.

this, however, since six points are subtracted from her score (see below) each time this option is used. In the same way, information regarding the patient's blood pressure can be obtained by selecting the proper option on the display.

Once a diagnosis is established, which may include rhythm, blood pressure, technical quality of the tracing, etc., action can be taken by choosing the medication or procedure option. If medication is indicated, the nurse may select a drug from a list offered to her by the program, which includes digitalis, vasopressors, atropine, isoproterenol, lidocaine, procainamide, and quinidine (Fig. 10). If a specific procedure is in order, such as cardioversion, carotid sinus pressure, or the use of a pacemaker, this can be entered through the numerical keyboard by pressing the numbered key corresponding to this option. If noise is present, it can be cleared by choosing the option labeled CHECK ELECTRODES. When a therapeutic decision is made and the corresponding action taken, a transition to a new condition will occur based on a random selection from the appropriate segment of the transition matrix, as explained below.

The program keeps a running score, based on the appropriateness of the decisions made, and continually displays this on the upper part of the scope (see below). If no decision regarding treatment is made by the nurse after two to four sweeps of the oscilloscope, the patient's condition will change again based on other elements in the transition matrix which reflect the expected natural course of the existing condition. If no treatment is instituted promptly in conditions such as ventricular fibrillation or hyperkalemia, a message on the

ated in the program to choose which condition according to these probabilities will be the new status of the patient.

To generate a random number, the computer samples the current reading of its internal 10-kc clock and masks out everything but the last six bits (this will be a number between zero and 77 octal). This number will be random because the time between clock readings is variable due to the fact that it includes the time for the student to make his decision. The algorithm by which the computer selects the next state involves comparing this random number to the first probability in the appropriate segments of the table. If this probability is less than the random number, the second probability from the table is added to the first and another comparison made. If the sum is greater than the random number, the state corresponding to the second probability is chosen. As a specific example, if condition A were atrial fibrillation with rapid ventricular response (which diminishes ventricular filling and causes a fall in cardiac output and systemic hypotension [8]) the best action would be to use the dc cardioverter. This is not the only available effective treatment, however, but the one that has the highest probability of restoring normal sinus rhythm and normal blood pressure under these circumstances. However, in spite of this being the optimal choice in most cases with this set of circumstances, the procedure may induce ventricular fibrillation, because of a nonsynchronized discharge in the vulnerable phase [9, 10], or any other known or unknown factor [11]. Even if ventricular fibrillation does result, this treatment in general is the best choice and the student's score

NEW STATE	TREATMENT									
	VENT. FIB	SINUS BRADY	SINUS BRADY	PVC's	SINUS BRADY	PVC's	V. FIBR	V. TACHY	V. FIBR	1° AV BLK
PRESENT STATE	VENT. FIB	NSR	NSR	NSR	NSR	NSR	NSR	NSR	NSR	NSR
	PVC	NSR	NSR	NSR	NSR	NSR	NSR	NSR	NSR	NSR
	VENT. TACH.	NSR	NSR	NSR	NSR	NSR	NSR	NSR	NSR	NSR
	A. FIB	NSR	NSR	NSR	NSR	NSR	NSR	NSR	NSR	NSR
N	+	+	+	+	+	+	+	+	+	+
O	+	+	+	+	+	+	+	+	+	+
R	+	+	+	+	+	+	+	+	+	+
L	+	+	+	+	+	+	+	+	+	+
D	+	+	+	+	+	+	+	+	+	+
U	+	+	+	+	+	+	+	+	+	+
S	+	+	+	+	+	+	+	+	+	+
P	+	+	+	+	+	+	+	+	+	+
T	+	+	+	+	+	+	+	+	+	+
R	+	+	+	+	+	+	+	+	+	+
A	+	+	+	+	+	+	+	+	+	+
E	+	+	+	+	+	+	+	+	+	+
N	+	+	+	+	+	+	+	+	+	+
E	+	+	+	+	+	+	+	+	+	+

Fig. 12. Transition matrix.

the patient with condition X is likely to find himself if he only receives treatment Y. A series of probability tables in the program determine the conditions that may result from the user's action. For instance, if the patient has developed arrhythmia A and the student chooses to institute therapy B, there is a high probability that the patient will go to condition D, a lower probability that he will go to condition E, a still lower probability of F, and zero probability of going to any of the other conditions in the table. A random number is gener-

is increased accordingly. The same may apply to quinidine-induced ventricular fibrillation [12], procainamide-induced hypotension [13], or a junctional tachycardia secondary to digitalis therapy [14, 15]. In this teaching program all these factors are taken into consideration in the scoring mechanism and a positive number is added to the score when the decision made is a good one, regardless of what happens to the patient in the particular case. As another example to illustrate the point consider a hypotensive patient given isoproterenol when sinus bradycardia is present. In most cases the program will make him normotensive at the next transition. However, there is a real but small probability that ventricular tachycardia (or supraventricular with aberrant ventricular conduction) will result even though the score paradoxically increases. Similarly, a negative number is added to the score when the action taken is not a good one.

With each decision a new score (NS) is calculated from the old score (OS) according to the formula

$$NS = OS + 6(DX/DXM - 0.5) \quad (1)$$

where DX is a decision function defined by

$$DX = PX - PRX \quad (2)$$

PX (benefit factor) is the probability that the chosen treatment will result in transition to normal sinus rhythm and normal blood pressure, and PRX (risk factor) is the probability of the chosen treatment resulting in ventricular fibrillation or ventricular tachycardia (whichever is greater). DXM is the decision function for the optimal RX (the one having maximum DX).

In those cases in which no treatment is indicated, taking no action will increase the score. However, when an active decision is in order, it has to be made promptly since a delay in applying the appropriate measures may result in rapid deterioration of the patient's condition and finally his death (with an accompanying low score). This feature puts pressure on the student to make decisions quickly as he or she must do in the coronary-care ward. Thus, the program becomes a realistic simulation of the situations commonly seen in a coronary-care unit and allows the students to make decisions which affect the subsequent course of the simulation.

The probability tables currently used in this program are based on a review of the current literature on the subject and the author's experience. These tables are only approximations to the actual probabilities but they will be modified and improved as further pertinent data are collected from coronary-care wards; the transition matrix provides an explicit format for this data collection. The program is flexible enough that new drugs or procedures can be added to the matrix, others can be deleted or changed and new tracings can be generated to represent additional arrhythmias, when this is desirable.

Figure 13 shows a segment of a probability table corresponding to the specific situation of a patient with atrial flutter. In the first row, the symbol TAB12 references the computer to a location in magnetic core where this segment of the table is located, the 1 indicating that this table refers to a drug in the medication list and the 2 defining this drug as quinidine. If the student elects to administer quinidine to the patient,

PROBABILITY TABLE FOR QUINIDINE IN
ATRIAL FLUTTER

TAB12	OCT 40001013	NORMAL BP	- NO DIGITALIS
	OCT 20004013	LOW BP	- NO DIGITALIS
	OCT 6000	NORMAL BP	- DIGITALIS
	OCT 40001002	LOW BP	- DIGITALIS

Fig. 13. Probability table.

the program will reference one of the four cells in memory that form this segment of the table, according to the patient's condition at this time. The first and second and the fifth and sixth octal digits in each row indicate the probability that the administration of quinidine will cause the patient to go into the state indicated by digits 3-4 and 7-8, respectively. For instance, if this patient with atrial flutter receives quinidine when his blood pressure is normal and he has already been digitalized, the program will reference the third line of the table segment shown. The octal digits 6000 indicate that there is a 60/80 probability that he will go to condition 0 (normal sinus rhythm) at the next transition and an implied 40/80 probability that his condition will not change. If he has not been digitalized, the first line in this segment of the table will be referenced and there will be 40/80 probability of reverting to normal sinus rhythm (4000), a probability 10/80 of going to condition 13, which is atrial fibrillation with rapid ventricular response (1013), and an implied 30/80 probability that the rhythm will not be affected unless further action is taken. The second and fourth line in this segment illustrate the transitions that may take place when the patient is hypotensive (condition 02 being atrial fibrillation with slow ventricular response).

Certainly a limiting factor in the quality of patient care in a coronary-care unit is the quality of the decisions made by the staff. This program is designed to give the nurse a concentrated experience in making these decisions based on realistic data. A program is only as good as its ability to represent reality both in terms of the variety of the arrhythmias presented, the probabilistic nature of the transitions made and the fact that these transitions are based on real observations. In any given clinical situation the therapeutic decision is based on the assumption that this case will behave like the average case in the same situation. In the simulation program, however, the user is made aware that there are other possible responses, as is often the case in real life, and is allowed to gain experience in making these vital decisions without risking someone's life until he has optimized his decision-making capabilities, as nearly as possible.

The practical use of this program in the training of nurses already working or being trained to work in coronary-care facilities during the past several months has been very satisfactory. More than 150 nurses trained and tested to date have shown definite improvement in their ability to make an adequate decision after properly evaluating the patient's situation in a short time, as evidenced by their ability to improve their scores using the simulation method.

In conclusion, it should be mentioned that as the simulation of the coronary-care unit becomes a more accurate reflection of reality it will also become a useful on-line tool for informing the nurse or the physician as to what action is

the most adequate in a given situation. This will occur when machines become less expensive and the data base more adequate for performing this decision-making process.

VII. EFFECTS ON HOSPITAL PERSONNEL

It is interesting to reflect on the changes that have occurred in the attitudes and goals of the people involved in this project. Initially it was hoped that the computer monitoring, by relieving the nurse of some routine measurement duties, might provide her with some free time, and thus decrease the number of nurses required to care for these patients. However, this has not been the case. Even though the nurse is relieved from some of her monitoring and recording duties, she is busier than ever, as is the doctor. The reason for this lies in the fact that they now know much more about their patient, and are forced to make many more decisions than before when they were, to a greater extent, in the dark about what was going on physiologically.

Even though the physiologic data are screened to present only that information which indicates a statistically significant physiologic change, the job of interpreting this change and the intellectual task of deciding what to do about it is one we are not as yet qualified to perform well. Even with 2 years experience with this system, many situations still arise which not only the nurse but also the doctor have difficulty in interpreting. It is for this reason that we are accumulating, in parallel with the physiologic data, as much clinical information as possible, in the hope that in time we will develop sufficient correlative information to permit the computer to assist us in

more accurate interpretation of the clinical meaning of the data with which we deal.

Although the monitoring system is continually evolving to include additional variables such as pH, pCO_2 , and pO_2 , which were recently added, even at this point in time it has proven its usefulness and does contribute to better patient care. Perhaps the best evidence of this is the fact that some surgeons doing open-heart surgery will now postpone a case if, for some reason, the computer monitoring system is not available.

This transition from emphasis on largely routine and somewhat mechanical activities to sometimes difficult intellectual effort is not an easy one for the nurse to make. It does require considerable retraining and shift of emphasis. The advent of the computer can be expected to bring equally drastic changes to the physician as well, as he begins to allocate more and more of the routine aspects of information storage, pattern recognition, and diagnosis to the machine, and finds himself spending more time dealing with creative and sometimes difficult new aspects of the world of medicine.

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